A STUDY OF THE TRAFFIC CAPACITY OF RAILWAYS BY THE APPLICATION OF THE RELATION BETWEEN DELAYS TO TRAIN OPERATION AND NUMBER OF TRAINS OPERATED

BY
WAN-CHIU CHANG
B.S., National Sun Yat-Sen University, 1936
D.I.C., Imperial College of Science and Technology, 1939
M.S., University of Illinois, 1940

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SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
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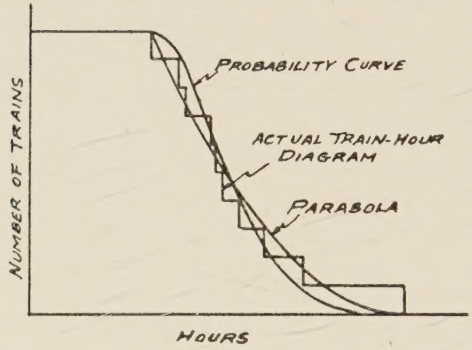
I. Introduction

After a railroad has been built, it happens very often that an increase of its traffic carrying capacity is demanded. Such demands may be due to the growth of population, the establishment of new industries, the change of political situation or the requirement of military action. In short, any change of social condition might effect the public demands on the service of a railroad, whether the change is from economic, political or military influence. When an engineer is facing the problem of increasing the traffic of a railroad, the items which come first into consideration would be the elimination of heavy grades and sharp curves, the improvement of track construction, the increase of motive power capacity by various means, the adoption of better rolling stock, the installation of modern signaling systems, and the desirability of the construction of additional track, etc. It might be desirable to have yards and terminals improved if the capacity is found to be limited by them. To this end, the problem arises at once: How does an improvement affect the traffic capacity? Is that improvement justifiable economically?

The purposes of this thesis is to investigate some of the suggested methods of increasing traffic capacity, but the financial consideration is, in general, beyond the scope of investigation. The effects of different methods of improvement above mentioned are analyzed quantitatively in order to find out the approximate percentage of capacity increase secured by the provision of a new improved facility. In the whole discussion, the amount of traffic is assumed to be indef-

inite, that is, there will be a sufficient amount offered to utilize the facilities as far as they are available.

The term "traffic capacity" used in this thesis denotes the carrying capacity of railroads. It is most commonly measured by ton-miles per day per mile of track. The term "track capacity" denotes the number of trains that can be handled from one end to the other of a railroad per day. It disregards the train weight, therefore, the unit of measurement is trains per day or train-hours per day per mile of track. The track capacity when multiplied by the train weight will give the traffic capacity provided the former is measured in terms of trains per day.



Actual Train-Hour Diagram, Probability Curve, and Parabola

No investigation of probable performance of a railway in producing transportation can be made without consideration of the basic problem of train delays. Much attention has been given to this matter by appropriate committes of the American Railway Engineering Association and other investigators. The method of investigating delays is the plotting from records of actual train movements the "train-hour diagram", which shows that actual number of trains moved over a given section of track and the time required for each to traverse the division. Such a diagram is shown in the Figure. As a result of drawing large numbers of such diagrams from actual train-sheets, it is found that the train-hour diagram is well represented by a half of the probability curve or a parabola. The expression for which can be readily placed in mathematical form. In deter-

mining the proper coefficients for such a curve, an assumption is made that a certain percentage of the total number of trains moved requires the minimum running time, t_0, plus D hours of delays to traverse the division, and various other percentages require, for example, t_0 plus D_1, etc. Study of diagrams from existing records quickly shows the range of coefficients proper to use for divisions of certain track characteristics, a given number of trains, certain train loading, dispatching practices, etc. In the investigation of actual conditions it has been found that up to the limit of the data available to us, the total amount of delays is directly proportional to the number of trains operated over the track in a given time.

For investigating the theory of delays, access to train-sheets in the Superintendent's office of the New York Central at Indianapolis was obtained through the courtesy of Mr. J. H. Westbay, Special Engineer. Two hundred and forty-nine such sheets involving the movement of from 10 to 16 trains per day were used. By means of this theory, the influence on the number of trains operated due to the change of train-speed or reduction of delays can be analyzed by comparing different cases on the equal road-time basis.

The way to increase the traffic capacity is by either increasing the train speed or load. Decreasing the delays to train operation results in effective speed increases. The elimination of heavy grades will result in an increase of tonnage; or if the train weight remains the same, the train speed will be higher. Better track construction reduces the train resistance and hence increases the train weight or train speed or both. The adoption of heavier motive power results in a greater tractive effort, giving an increase in train weight or in train speed. The same result is expected from the improvement of rolling stock. Modernization of signaling systems increases the traffic capacity by reducing delays to train operation and thence increasing the average train speeds. It permits the dispatching of more trains than is possible without the new installation.

II. SUMMARY

By the use of a well-founded theory of delays to train movement, the writer believes that, in any analysis, the method of attack is sound and the operating conditions assumed are practical. Therefore, the procedures appear to be accurate and reliable. Methods of generalization have not been sought. Since local conditions on any given railway line introduce so many variables, that solutions of each problem in terms of fundamentals is a more dependable procedure. The results of the investigations are stated here by the way of summary:

(1) The actual train-hour diagrams can be fitted very well by either a probability curve or a parabola.

(2) The average delays to trains increase proportionally with the number of trains operated.

(3) The replacement of time-table, train-order, and manual block signaling system by the automatic block signaling increases the traffic capacity by an amount of 25 per cent. This results from reducing the meeting delays and the number of train-orders. When the centralized traffic control system is installed, the traffic capacity is increased more than 50 percent.

(4) The installation of interlocking plants reduces the number of stops at grade crossings, and hence the traffic capacity is increased. But the effiects are influenced by the existing signaling system. It is found that the increase of traffic capacity in a certain road is 3, 4, or, 6 percent by the installation of an interlocking plant when the signaling system of the road is manual block signaling, automatic block signaling, or "C. T. C." system respectively. The corresponding effect from grade separation is 12, 18, or 30 percent.

(5) The increase of track capacity from double tracking is a very complicated problem and there is no general principle to forecast such results. In an analysis, double tracking increases the theoretical track capacity from 0 to 200 percent of that of the existing track, when the added track is assumed to serve for trains in one direction, and the existing track for trains in the other direction.

(6) The effects from grade reduction depend on the ratio between the length of grade reduced and the length of the division. The larger is this ratio, the greater is the effect. The train speed is a factor which greatly complicates determining improvement from such a change.

(7) The elimination of curvature and "rise and fall" have positive effects on the traffic capacity of a railroad. The result of replacing the fluctuating grades by a uniform grade, in one case interpreted, is 9 percent increase in traffic capacity.

(8) Better track construction reduces the train resistance, and hence permits a higher train speed to increase the traffic capacity slightly. The replacement of 85 lb. rails on 6-in. x 8-in. x 8-ft. ties with 12-in. ballast by 130 lb. rails on 7-in x 9-in. x 8-ft. ties with 36-in. ballast increased the traffic capacity of a division from 7 to 15 perecnt, depending on the amount of delays in existence.

(9) The installation of more engines permitting increasing the number of trains operated does not necessarily increase the traffic capacity of the road. In case that the track is already heavily used by the existing trains, a further increase in number of trains will cause serious delays. It is possible, in such case, that the train load has to be reduced, for maintaining the over-all road time, to an extent that there results an actual reduction in traffic capacity.

(10) For any engine, there is a speed corresponding to maximum ton-miles per train-hour. But this speed is different from the speed corresponding to maximum ton-miles per day, when the track capacity of the road is taken into consideration. The former corresponds to developing the maximum traffic capacity of the engine, the latter for that of the road.

(11) The adoption of light-weight-construction and roller bearing journals expedites the train motion, and hence increases the traffic capacity by increasing the train speed. The use of light-weight cars would improve the traffic capacity by 8 to 12 percent with an amount of delays varying from 50 to 30 percent of the running time; but the roller bearing journals increase it by varying amounts at different speed, e.g., it is

42 percent at 30 m.p.h., and 16 percent at 35 m.p.h., with the amount of delays equal to 30 percent of the running time. When the running speed is at or above 40 m.p.h., the adoption of roller bearings shows no advantage.

(12) The increase of terminal delays means lengthening the average over-all road time. In one investigation, it is found that an increase of 15 minutes of terminal delays reduces the traffic capacity by 11 percent, and when the delays are 30, 45, or 60 minutes, the amount of reduction is 28, 43, or 57 percent respectively.

VITA

Wan-Chiu Chang was born in Canton, China, December 6, 1914. After his graduation from the Subordinate High School of the National Sun Yat-Sen University in Canton in June, 1932, he started his study in that University and received the degree of Bachelor of Science in Civil Engineering in June 1936. He then worked as Junior Engineer at the Peiping-Hankow Railway at Hankow and Fengchun from 1936 to 1937, and later received an appointment as teaching assistant in Civil Engineering at the Sun Yat-Sen University. Afterward, he served as Resident Engineer in the Leipoo-Wuchow Highway, Kwangsi, for a short period of time. In the summer of 1938, he was awarded a scholarship to study in England by the Chinese Central Government. He obtained the Diploma of Imperial College of Science and Technology, London, in June of 1939.

He was granted the degree of Master of Science in Railway Civil Engineering by the University of Illinois in June of 1940. Since that time, he has continued his graduate work at the University.